Fully automated adjustment of the electron beam line of the 2 MeV Electron Cooler at the Cooler Synchrotron @ FZ-Jülich

Arbeitskreis Beschleunigerphysik 5.3:
Beam and Accelerator Control I

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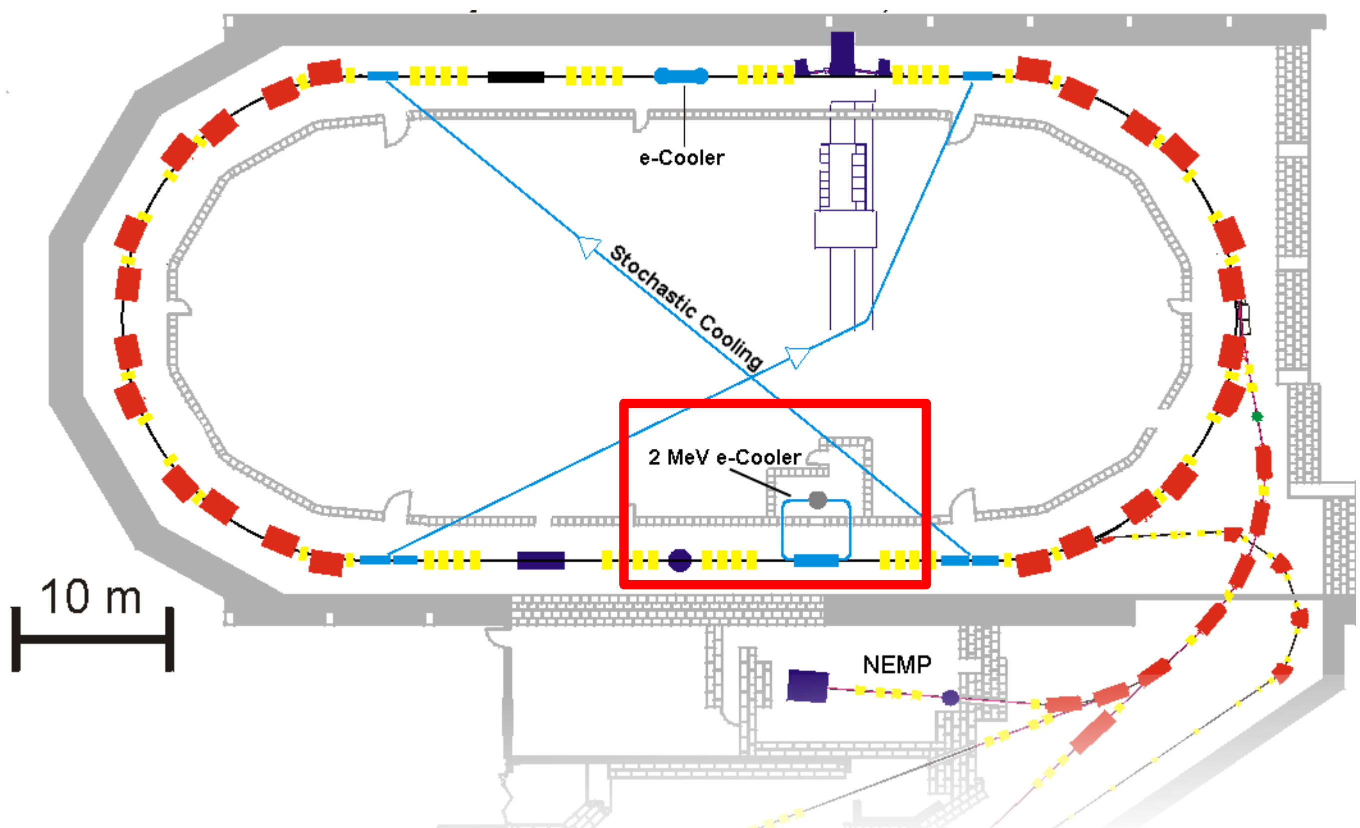
Contents

Cooler Synchrotron COSY

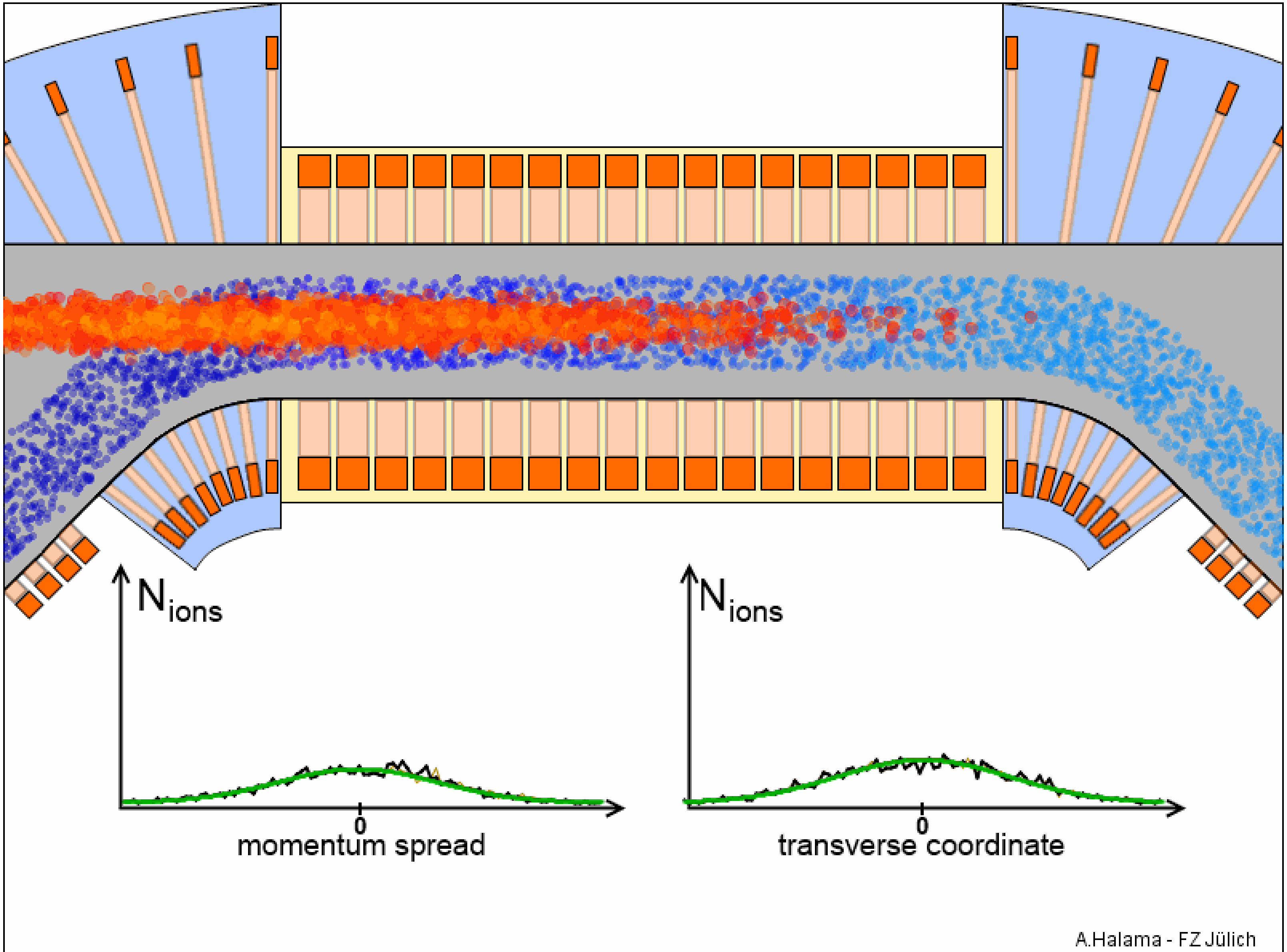
- Protons/Deuterons
- Unpolarized and polarized
- Stochastic and electron cooling
- Up to 2,8 GeV
- 184 m circumference



Source: COSY operating documents

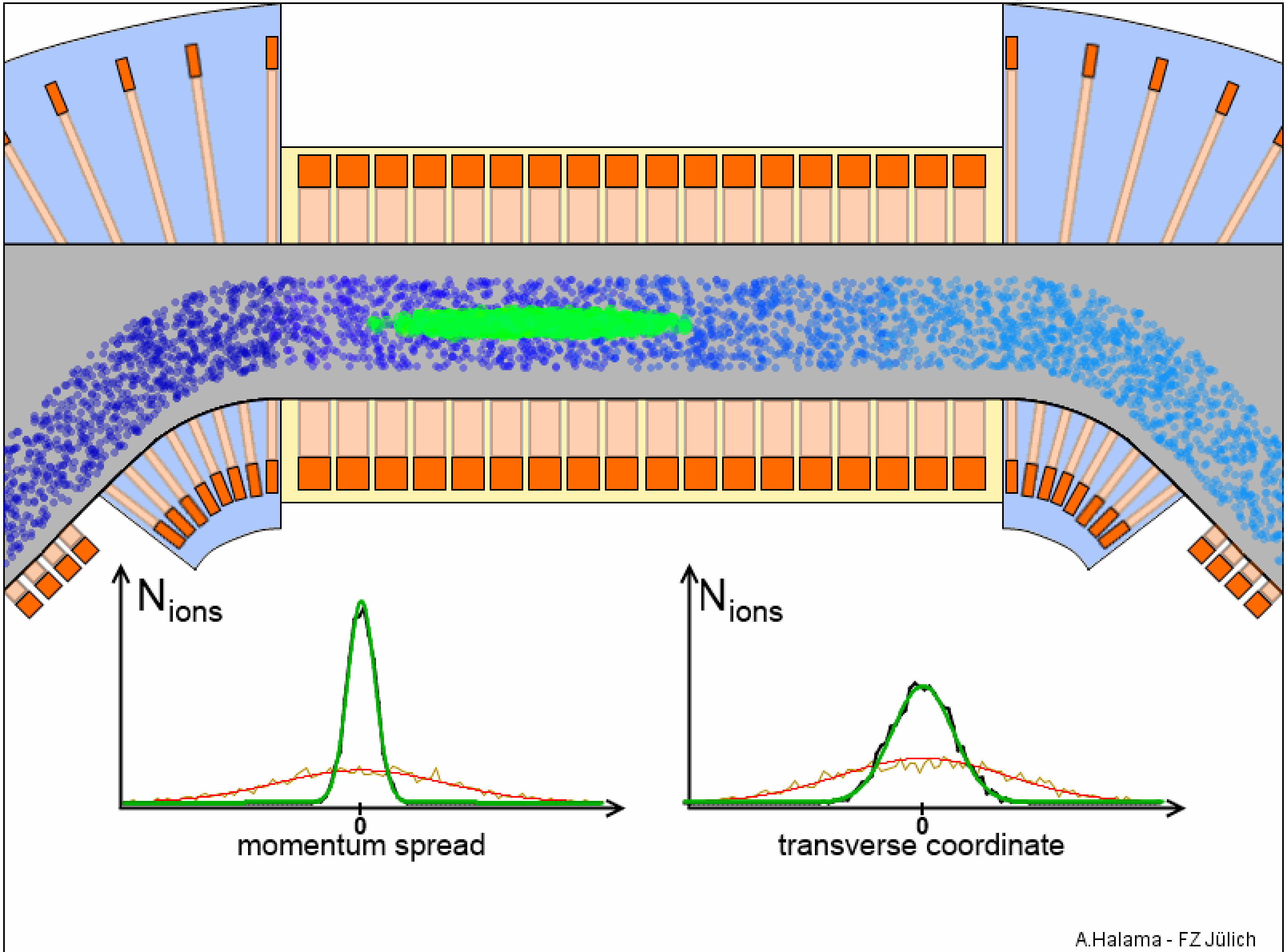
Electron beam cooling

$\overline{v}_e = \overline{v}_p$!

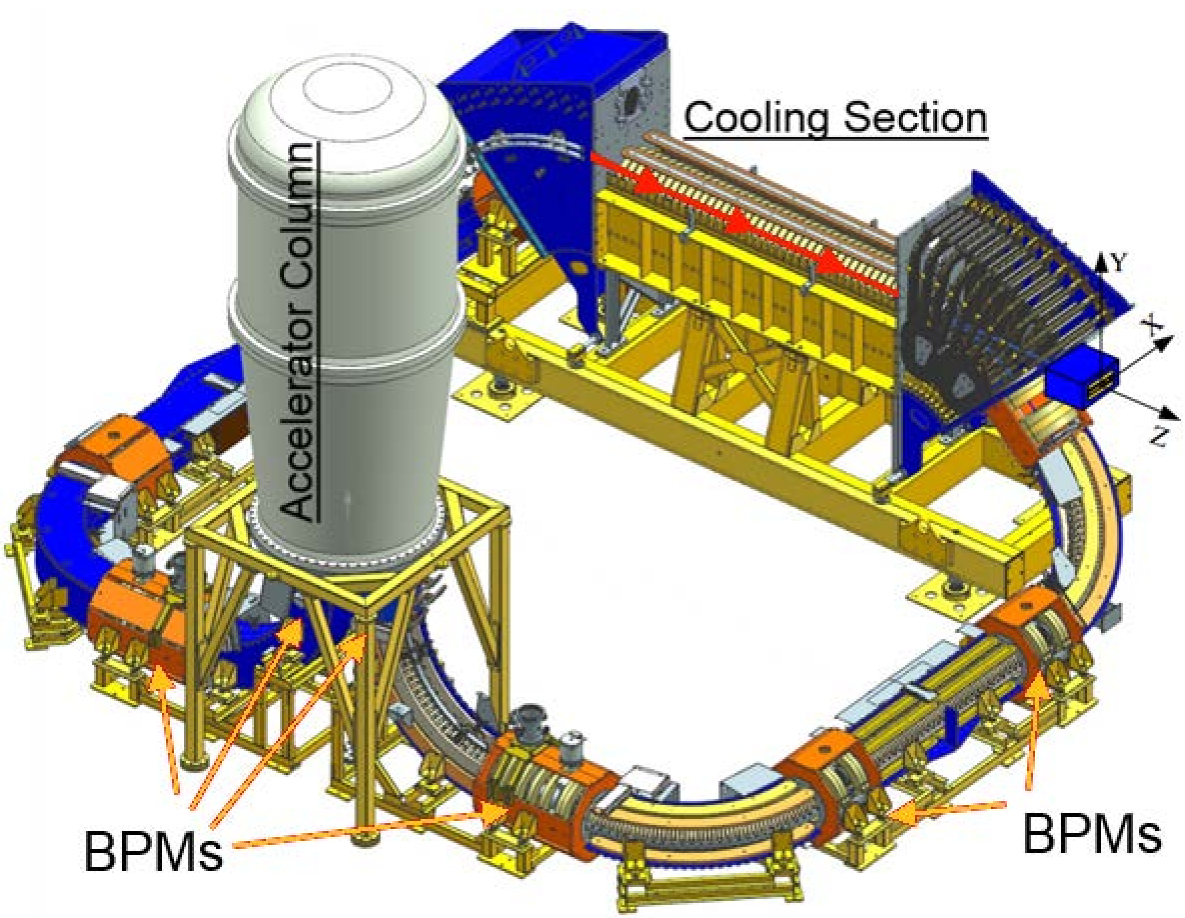


Electron beam cooling

$$\overline{v}_e = \overline{v}_p \,!$$



2 MeV electron Cooler



Design parameters

Energy range:

25 keV – 2 MeV

Current: 3 A

Longitudinal magnetic guiding field

12 pairs of BPMs

BINP SB RAS, Novosibirsk, Russia “Magnetic System of Electron Cooler for COSY”

Motivation

Status:

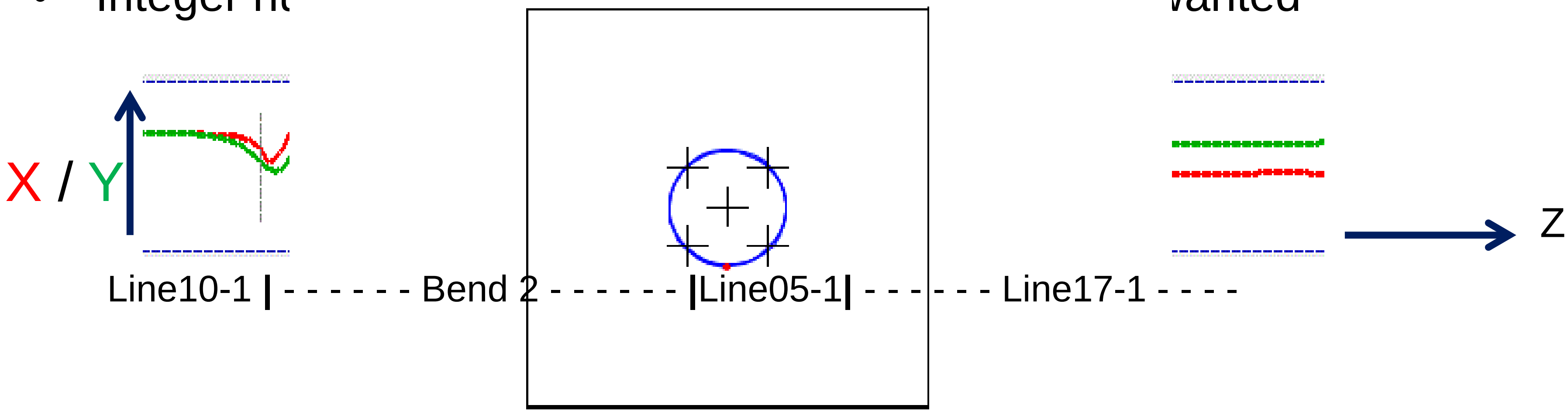
- Orbit adjustment is done manually
- Larmor motion can only be compensated in one section
- Larmor motion at other locations and galloping motion is not dealt with

Goal:

- Enhance cooling efficiency
- Higher beam current, allowed by higher recouperation rate
- Fast and reliable adjustment

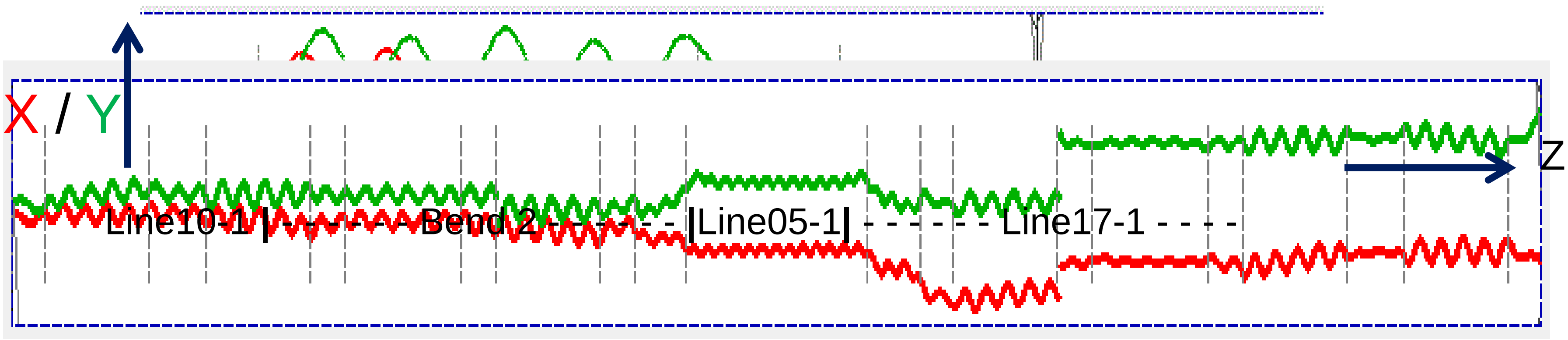
Larmor oscillation

- Coherent cyclotron motion superimposed with longitudinal propagation
- Mismatched magnetic sections (Bending) lead to coherent oscillatior
- Integer nu vanted



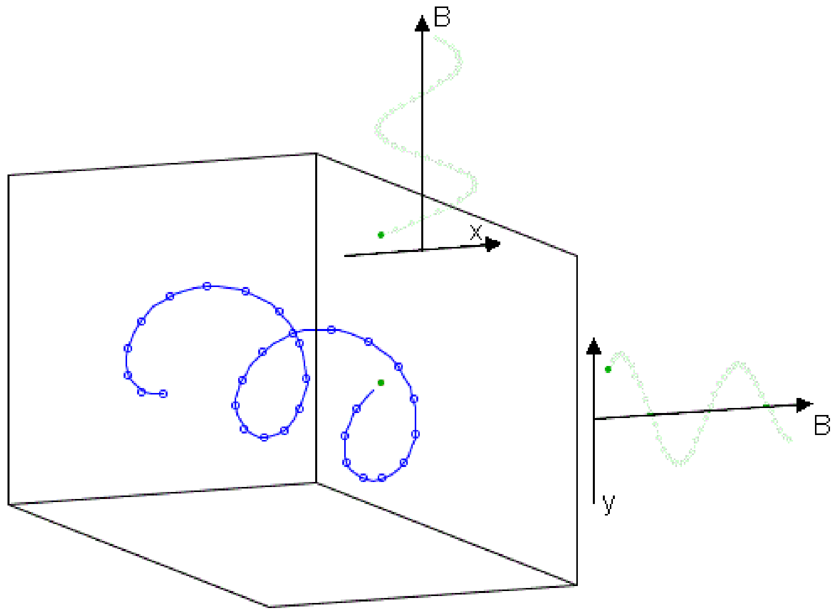
Larmor oscillation

- Coherent cyclotron motion superimposed with longitudinal propagation
- Mismatched magnetic sections (Bending) lead to coherent oscillation.
- Integer number of oscillation in bending sections is wanted



Varying longitudinal field in bending section from 267.3 A to 312 A

Larmor radius measurement



- Varying longitudinal field in straight section
- Logging beam position vs. changed field/current
- Amplitude = larmor radius

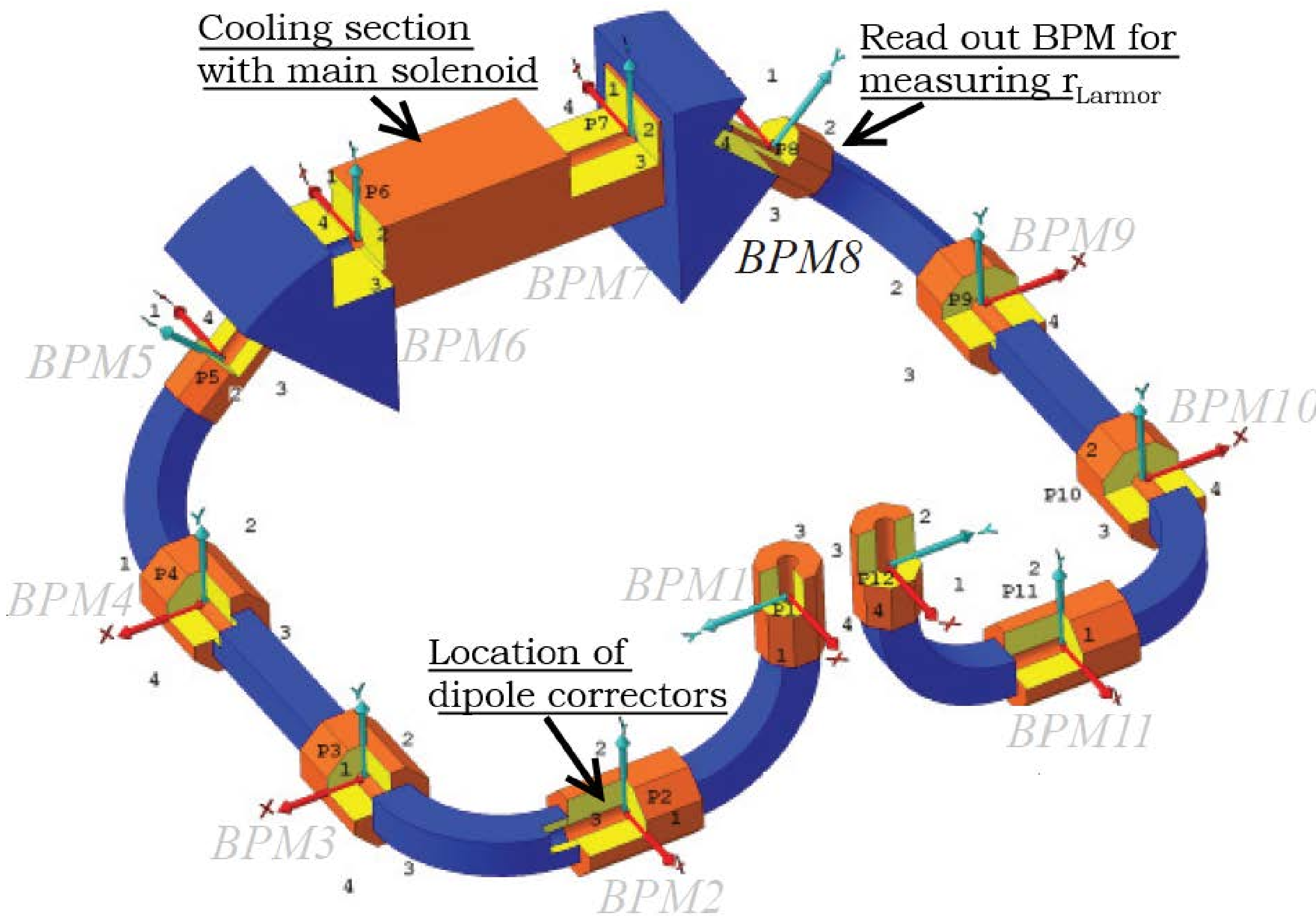
$$r_{Larmor} = \frac{\gamma m_0 v_\perp}{eB}$$

$$l_{Larmor} = v_\parallel \frac{2\,\pi\,\gamma\,m_0}{e\,B}$$

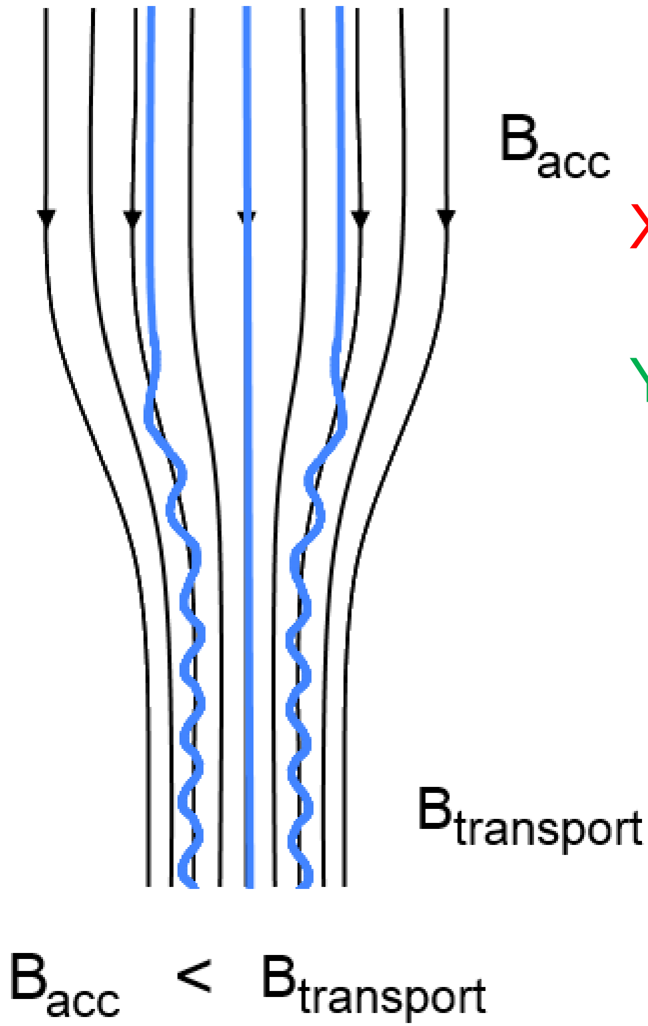
Larmor oscillation compensation

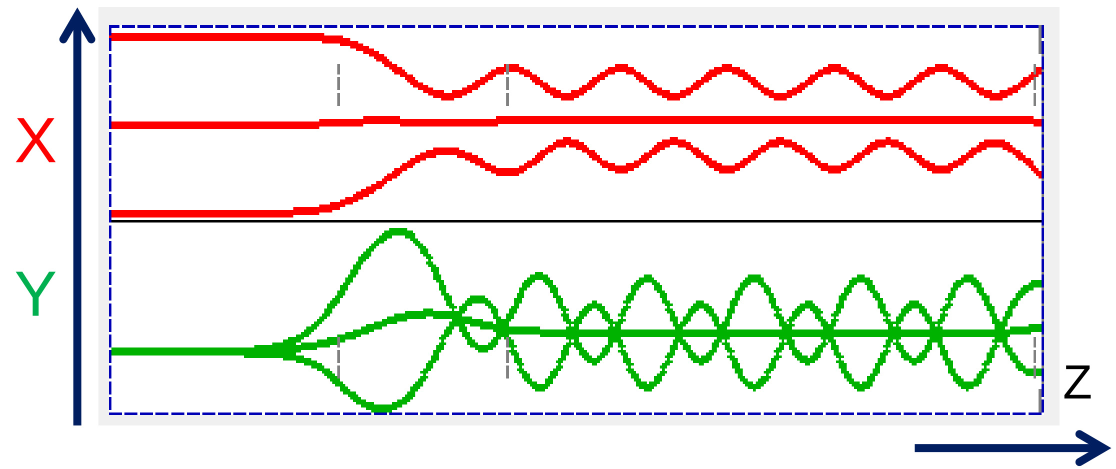
Short dipoles kick the beam specifically

Thus, decreasing larmor radius in cooling section



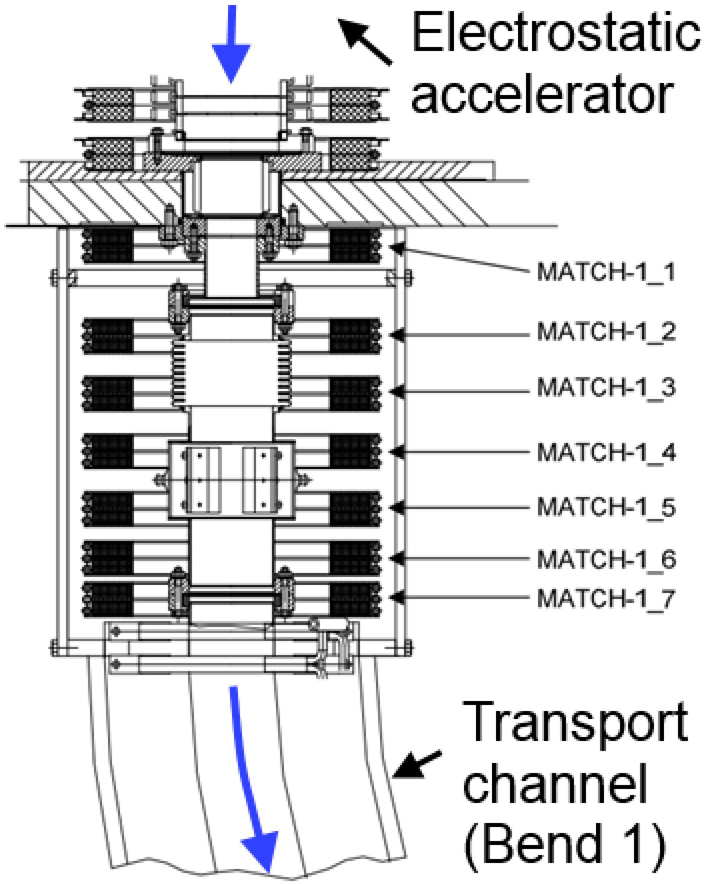
Galloping motion



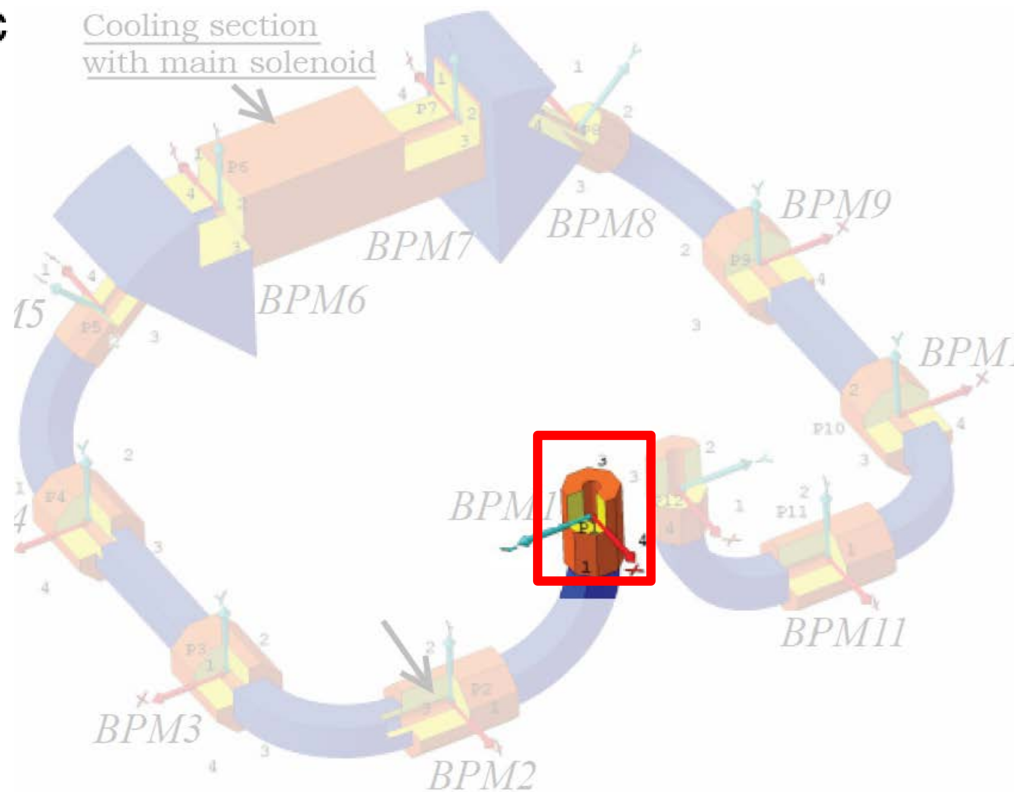


- Not coherent but deterministic
- Individual larmor oscillation grows with distance to center

Magnetic matching section to minimize heat up

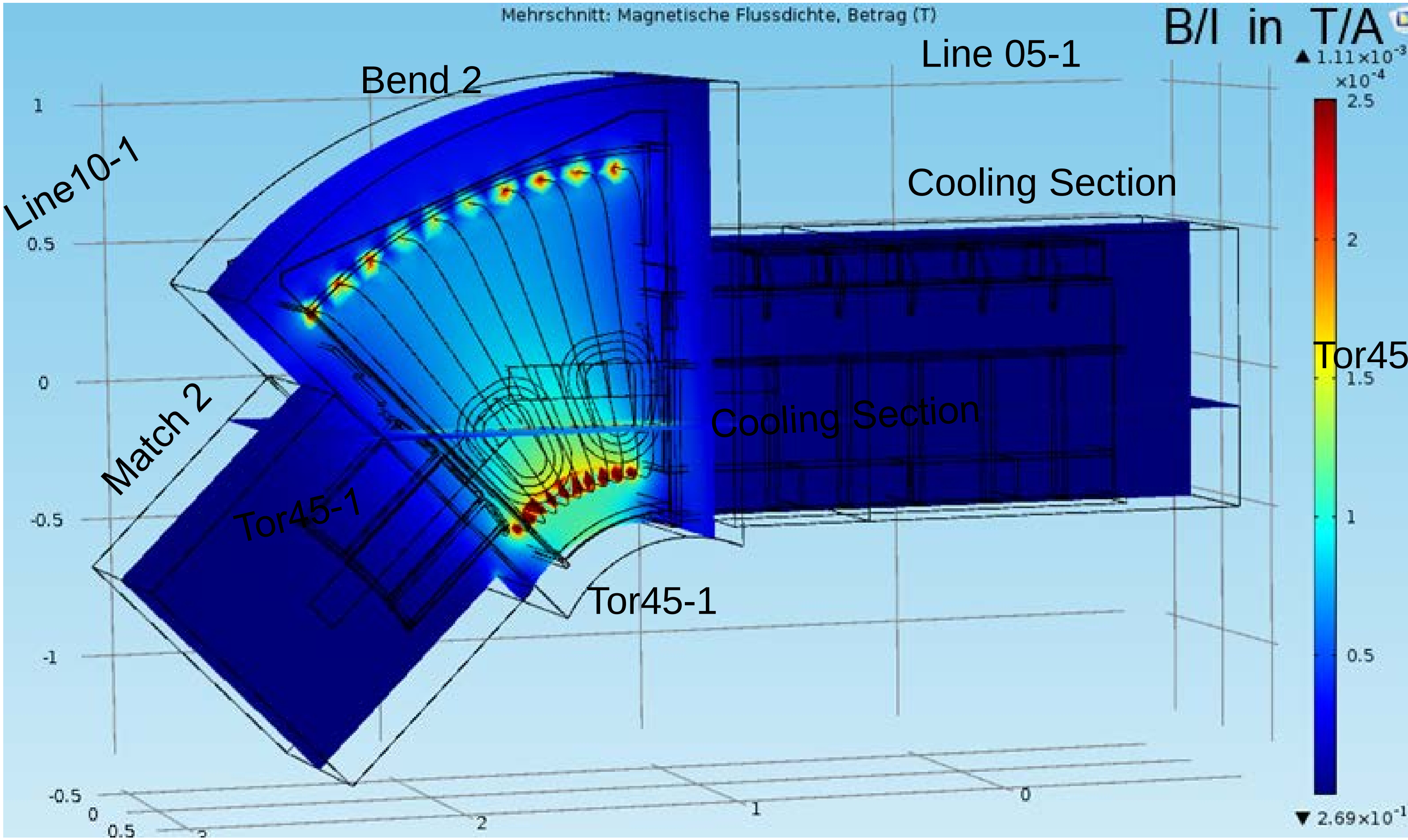


Matching section of the gun part.



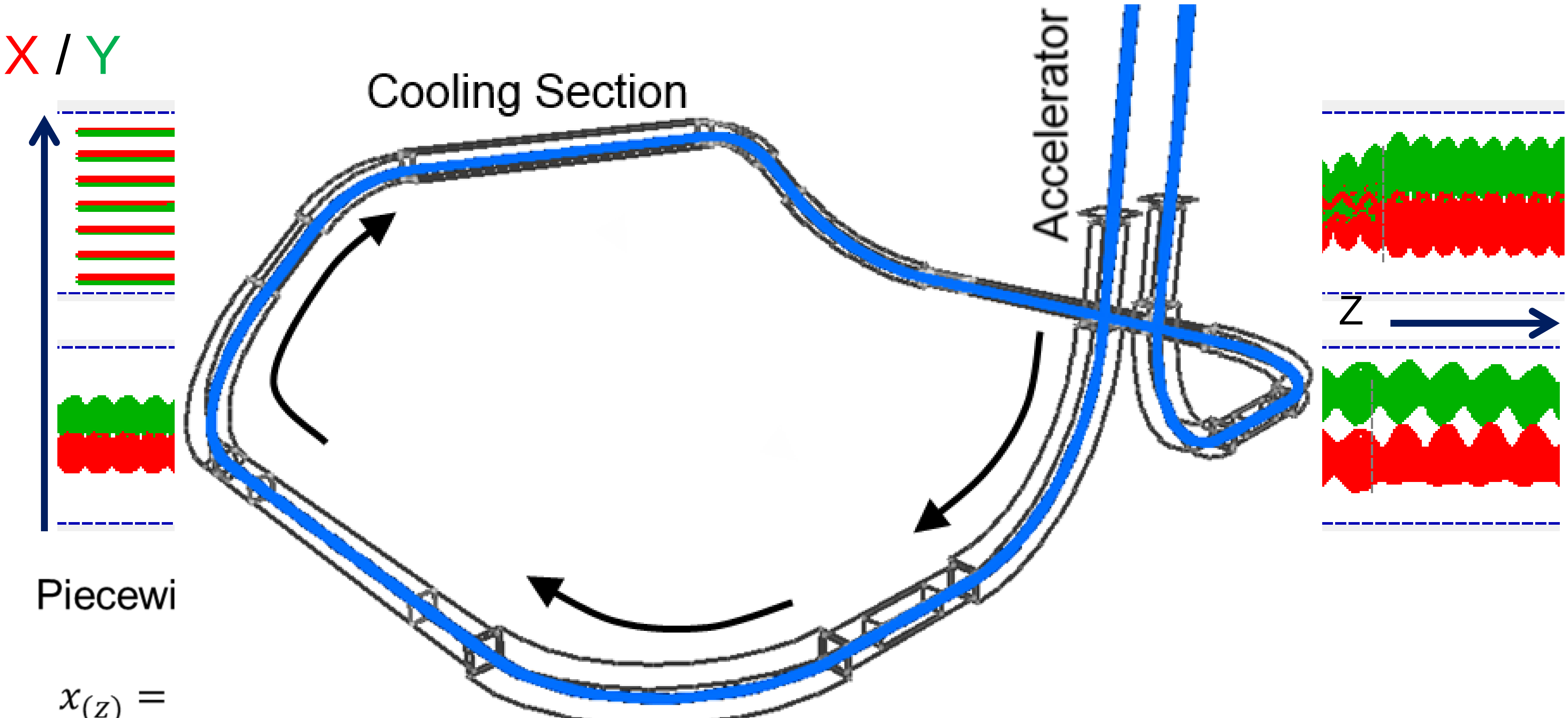
Source: Internal Documentation / Technical Drawings

Magnetic field maps



Time discrete trajectory simulation

Given an apropriate form of the equation of motion $F = \frac{dp}{dt} = q\,(E + v \times B)$



Piecewi

$x_{(z)} =$

$$y_{(z)} = y_0 + z\,m_y + A_Y \sin(k_m z) + B_y \cos(k_m\, z)$$

- Simulated electron trajectory

Status

- Simulated electrons in the entire energy range are guided through the whole structure
- Magnets behave as expected
- Single adjustments based on trajectory response work

First conclusion

- Beam behavior expectation allows adjustment of the 2 MeV cooler beam line (Orbit, Larmor, Galloping)

Plans for the near future

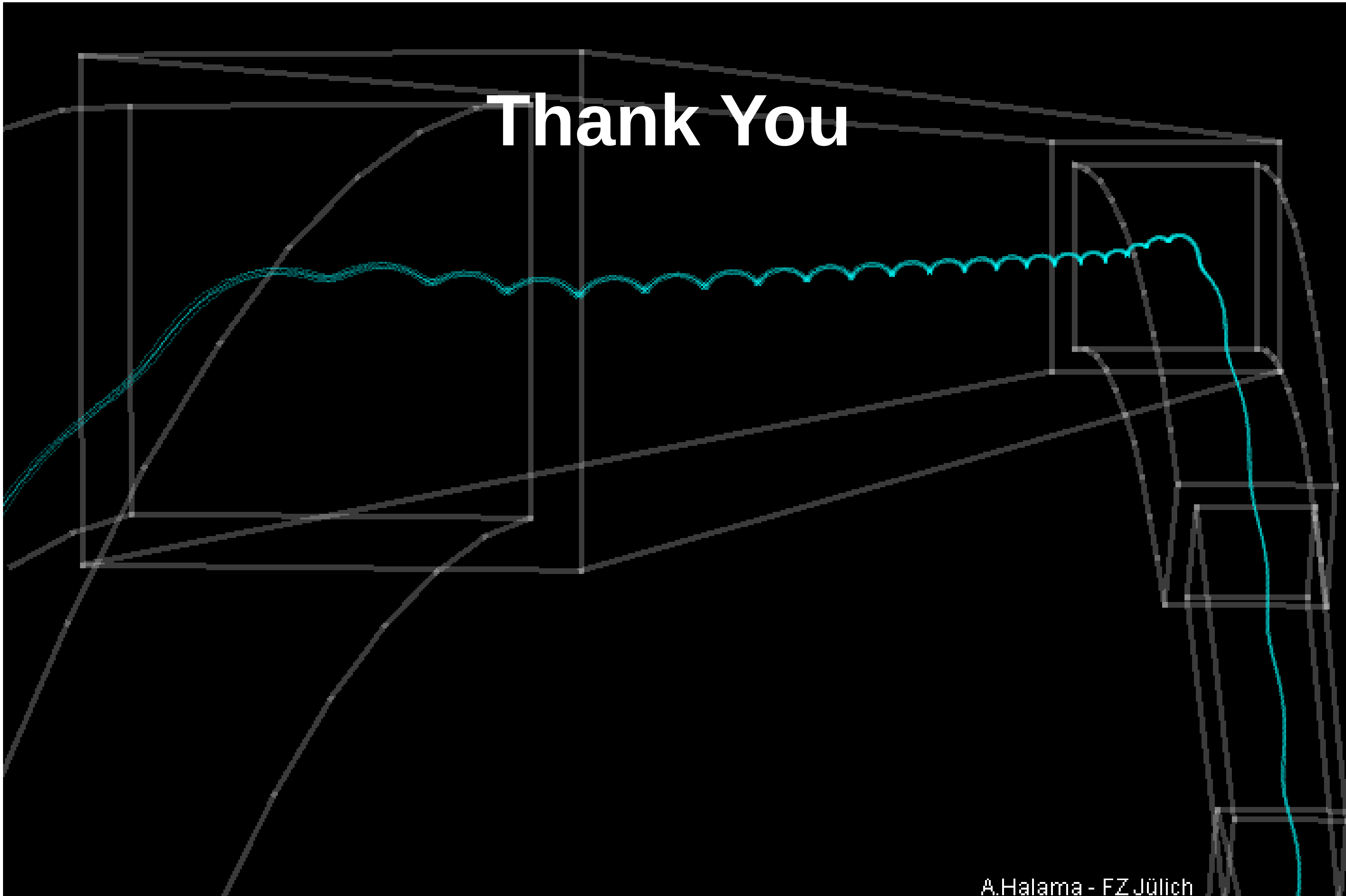
- Indroducing finer and more reliable field maps
- Study the actual 2 MeV Cooler to decrease dissimilarities
- Automatizing a sequencial adjustment

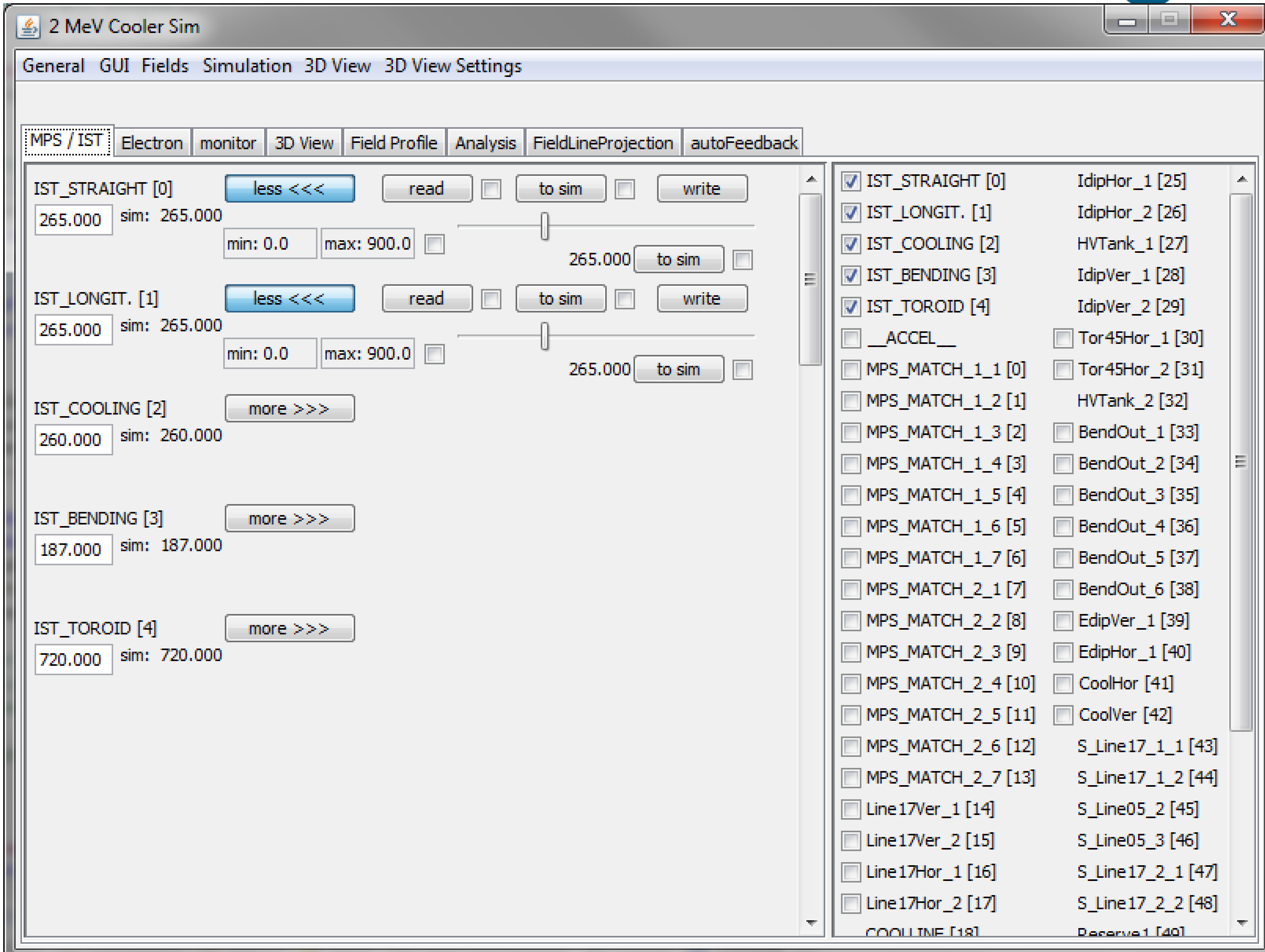
Outlook

- Integration of an in-situ feedback monitor
- Field tests and implementation
- Introduction of more acurate magnet model:
  - Linear model $\mathrm{B}(I)_{total} = (\frac{dB_{vac}}{dI} + \frac{dB_{shield}}{dI})I$ <- currently used
  - Saturation model: $\mathrm{B}(I)_{total} = \frac{dB_{vac}}{dI} I + B_{0\,shield}(1 - e^{-kI})$
  - Hysteresis model: $\mathrm{B}(I)_{total} = \frac{dB_{vac}}{dI} I + B_{0\,shield}\left(1 - e^{-kI}\right) + B_{rem}$

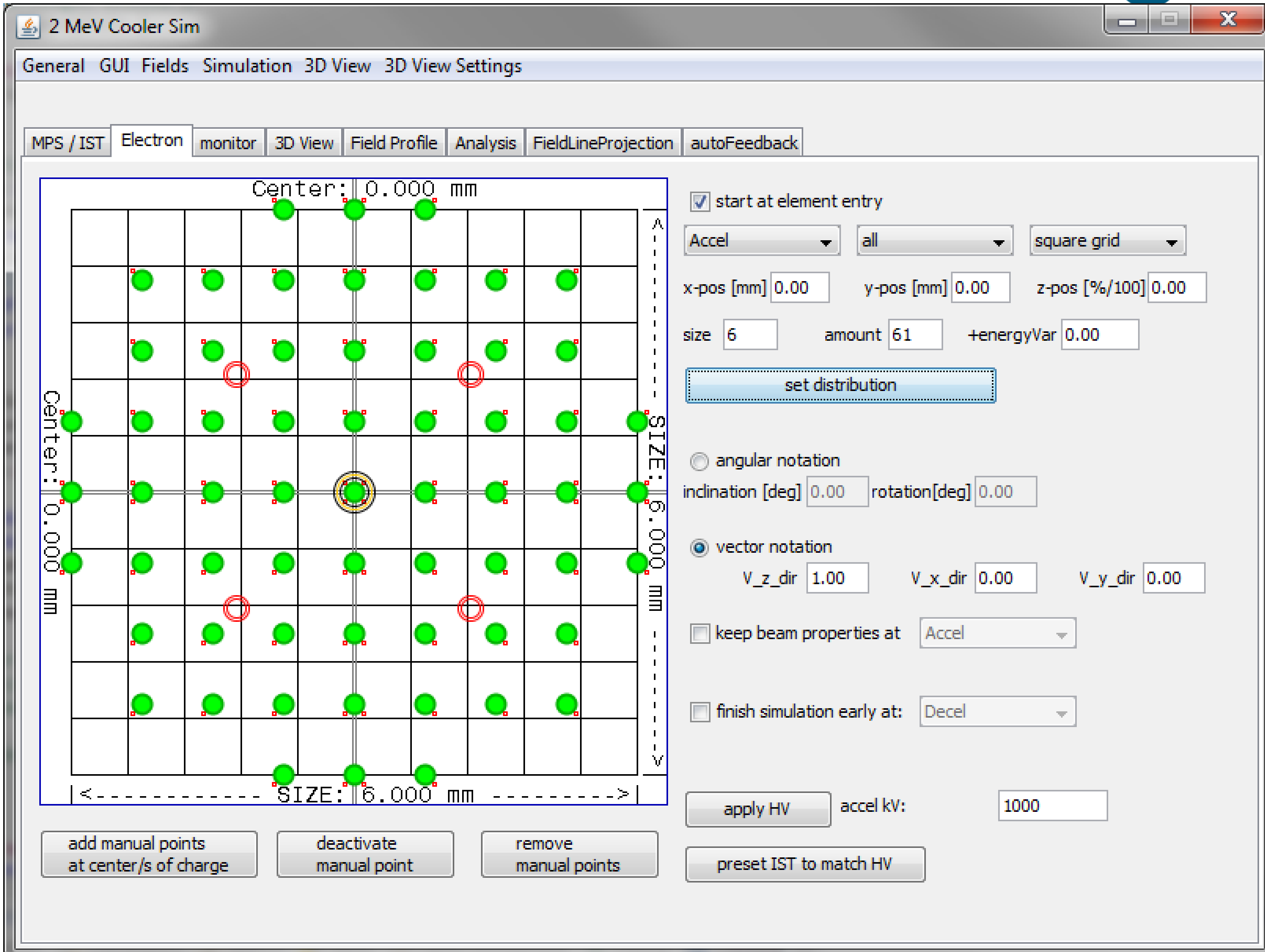
Mitglied der Helmholtz-Gemeinschaft

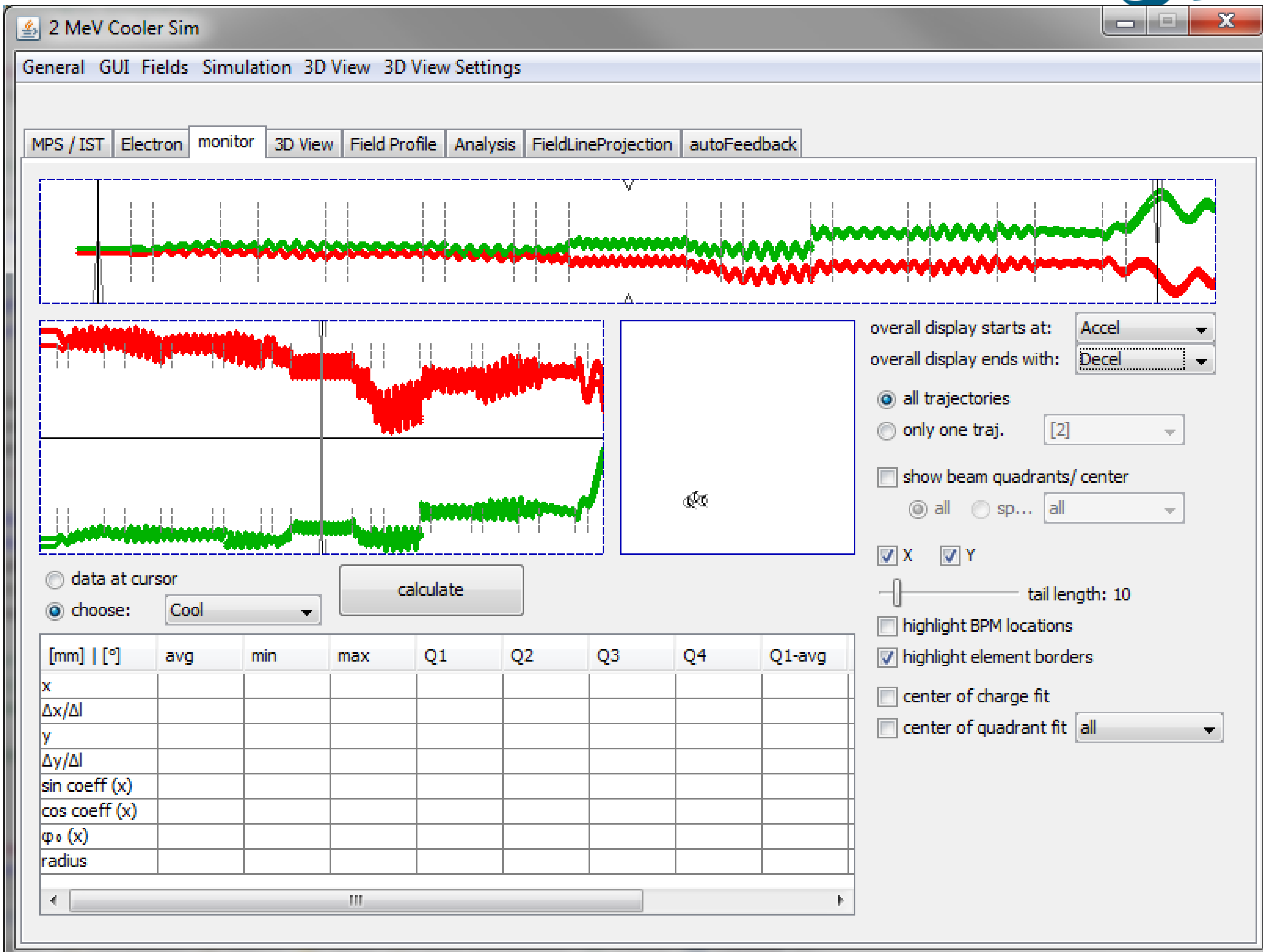
Thank You

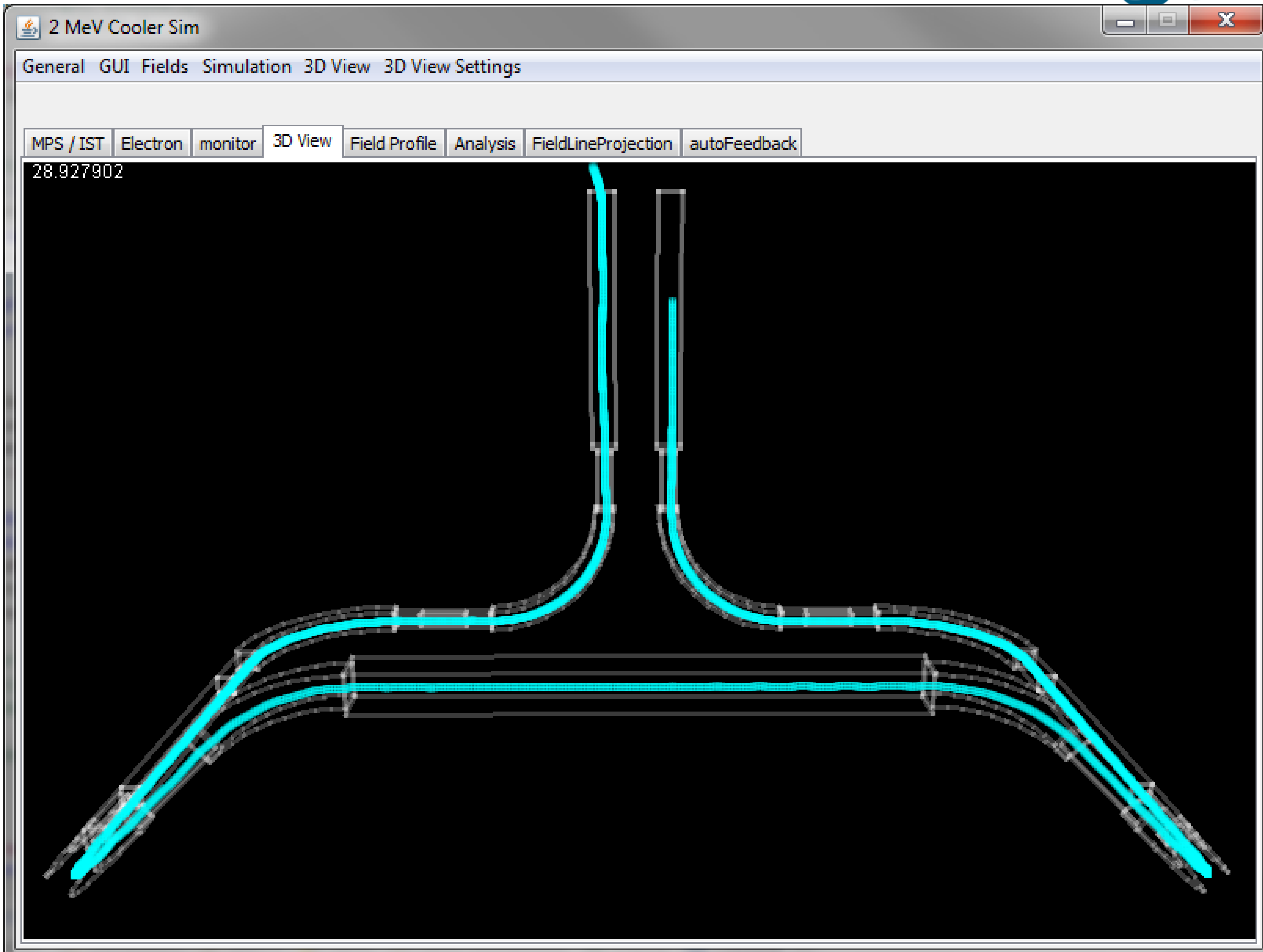




Mitglied der Helmholtz-Gemeinschaft


2 MeV Cooler Sim
General GUI Fields Simulation 3D View 3D View Settings
MPS / IST Electron monitor 3D View Field Profile Analysis FieldLineProjection autoFeedback
Center: 0.000 mm
Center: 0.000 mm
SIZE: 6.000 mm
SIZE: 6.000 mm
start at element entry
Accel
all
square grid
x-pos [mm] 0.00
y-pos [mm] 0.00
z-pos [%/100] 0.00
size 6
amount 61
+energyVar 0.00
set distribution
angular notation
inclination [deg] 0.00
rotation[deg] 0.00
vector notation
V_z_dir 1.00
V_x_dir 0.00
V_y_dir 0.00
keep beam properties at
Accel
finish simulation early at:
Decel
apply HV
accel kV:
1000
preset IST to match HV
add manual points at center/s of charge
deactivate manual point
remove manual points


2 MeV Cooler Sim
General GUI Fields Simulation 3D View 3D View Settings
MPS / IST
Electron
monitor
3D View
Field Profile
Analysis
FieldLineProjection
autoFeedback
overall display starts at: Accel
overall display ends with: Decel
all trajectories
only one traj. [2]
show beam quadrants/ center
all sp... all
X Y
tail length: 10
highlight BPM locations
highlight element borders
center of charge fit
center of quadrant fit all
data at cursor
choose: Cool
calculate
[mm] | [°] avg min max Q1 Q2 Q3 Q4 Q1-avg
x
Δx/Δl
y
Δy/Δl
sin coeff (x)
cos coeff (x)
φ₀ (x)
radius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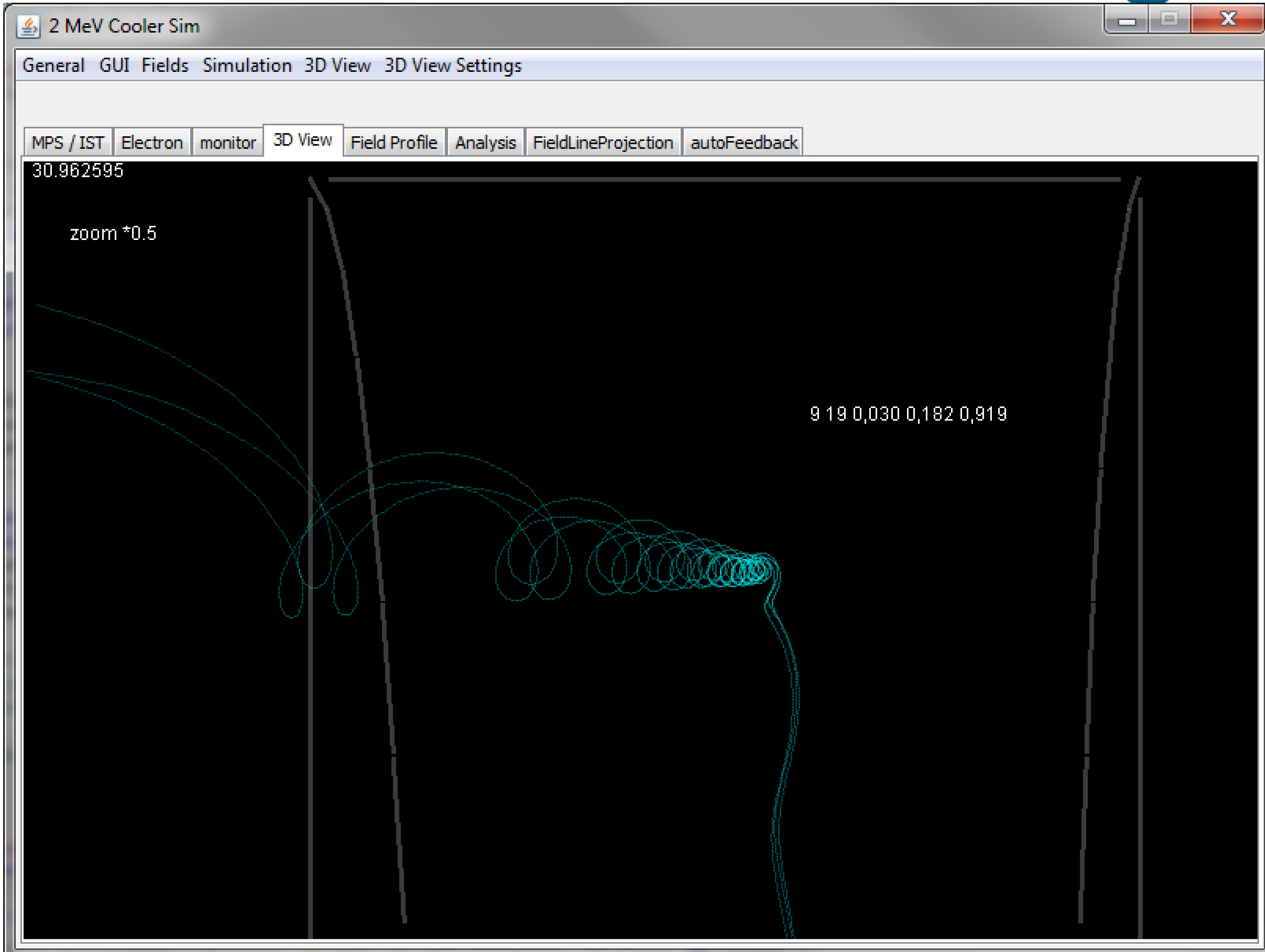
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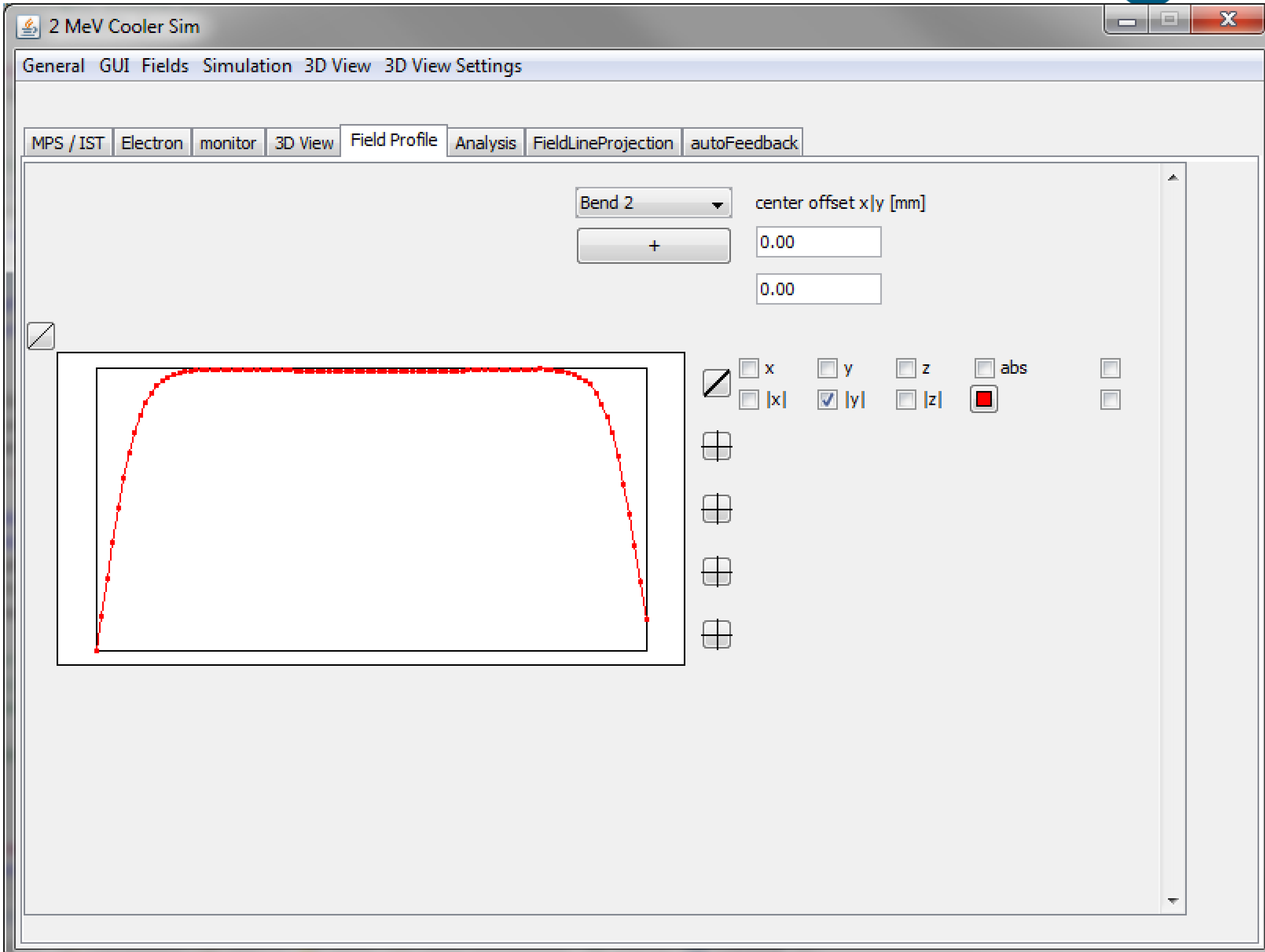
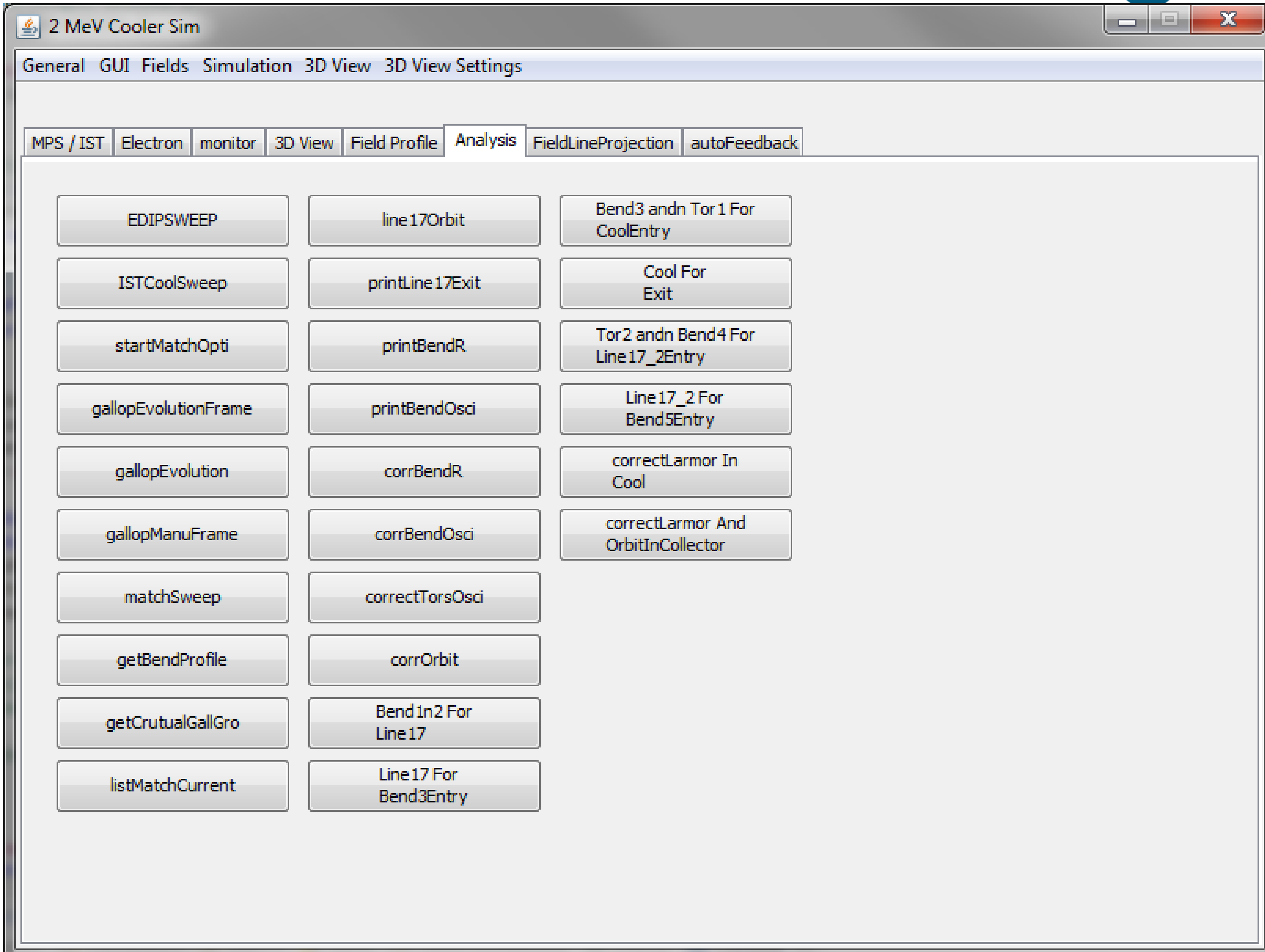
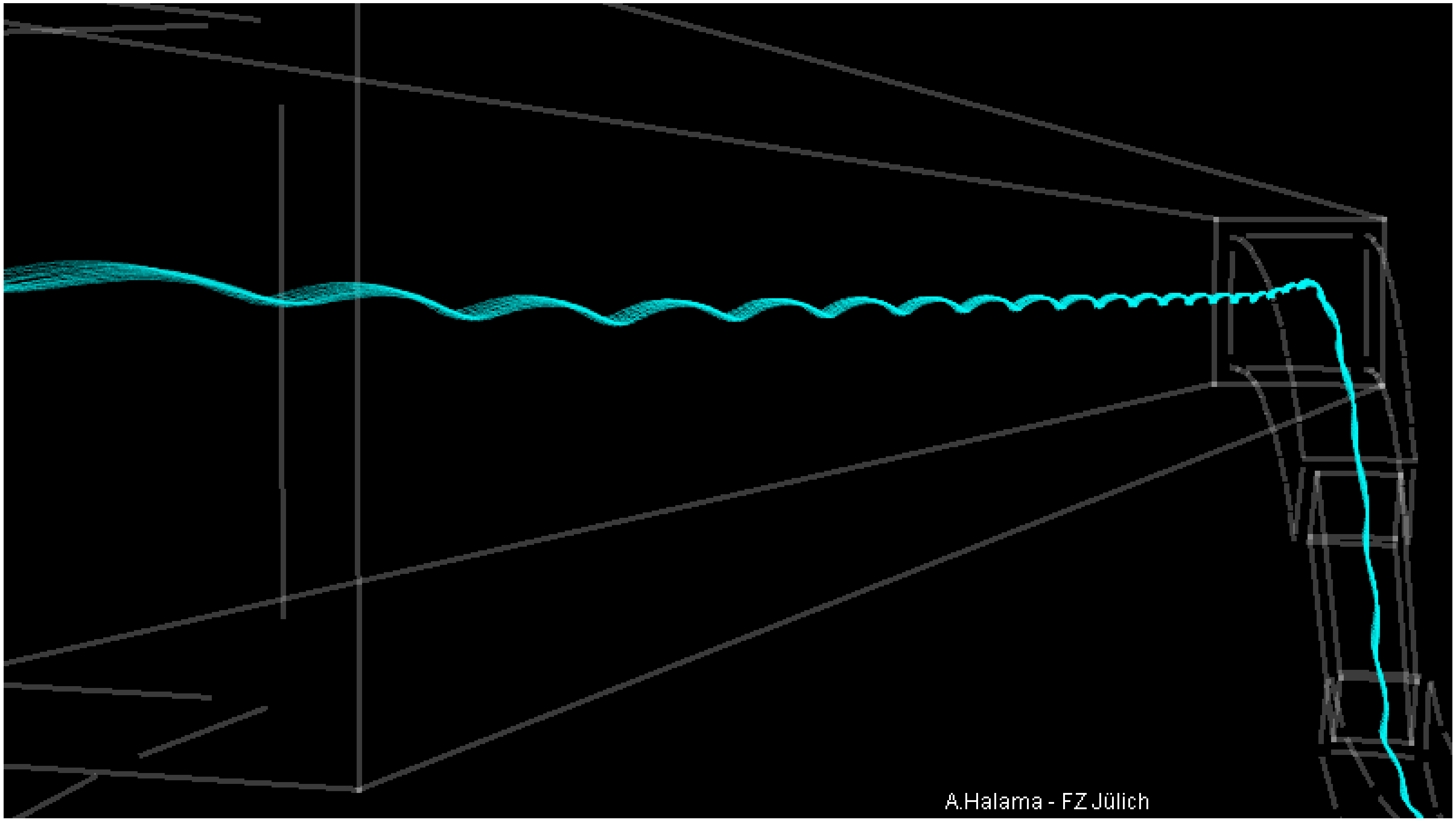
9 19 0,030 0,182 0,919


2 MeV Cooler Sim
General GUI Fields Simulation 3D View 3D View Settings
MPS / IST Electron monitor 3D View Field Profile Analysis FieldLineProjection autoFeedback
Bend 2
+
center offset x|y [mm]
0.00
0.00
x y z abs
|x| |y| |z|


2 MeV Cooler Sim
General GUI Fields Simulation 3D View 3D View Settings
MPS / IST
Electron
monitor
3D View
Field Profile
Analysis
FieldLineProjection
autoFeedback
EDIPSWEEP
line17Orbit
Bend3 andn Tor1 For CoolEntry
ISTCoolSweep
printLine17Exit
Cool For Exit
startMatchOpti
printBendR
Tor2 andn Bend4 For Line17_2Entry
gallopEvolutionFrame
printBendOsci
Line17_2 For Bend5Entry
gallopEvolution
corrBendR
correctLarmor In Cool
gallopManuFrame
corrBendOsci
correctLarmor And OrbitInCollector
matchSweep
correctTorsOsci
getBendProfile
corrOrbit
getCrutualGallGro
Bend1n2 For Line17
listMatchCurrent
Line17 For Bend3Entry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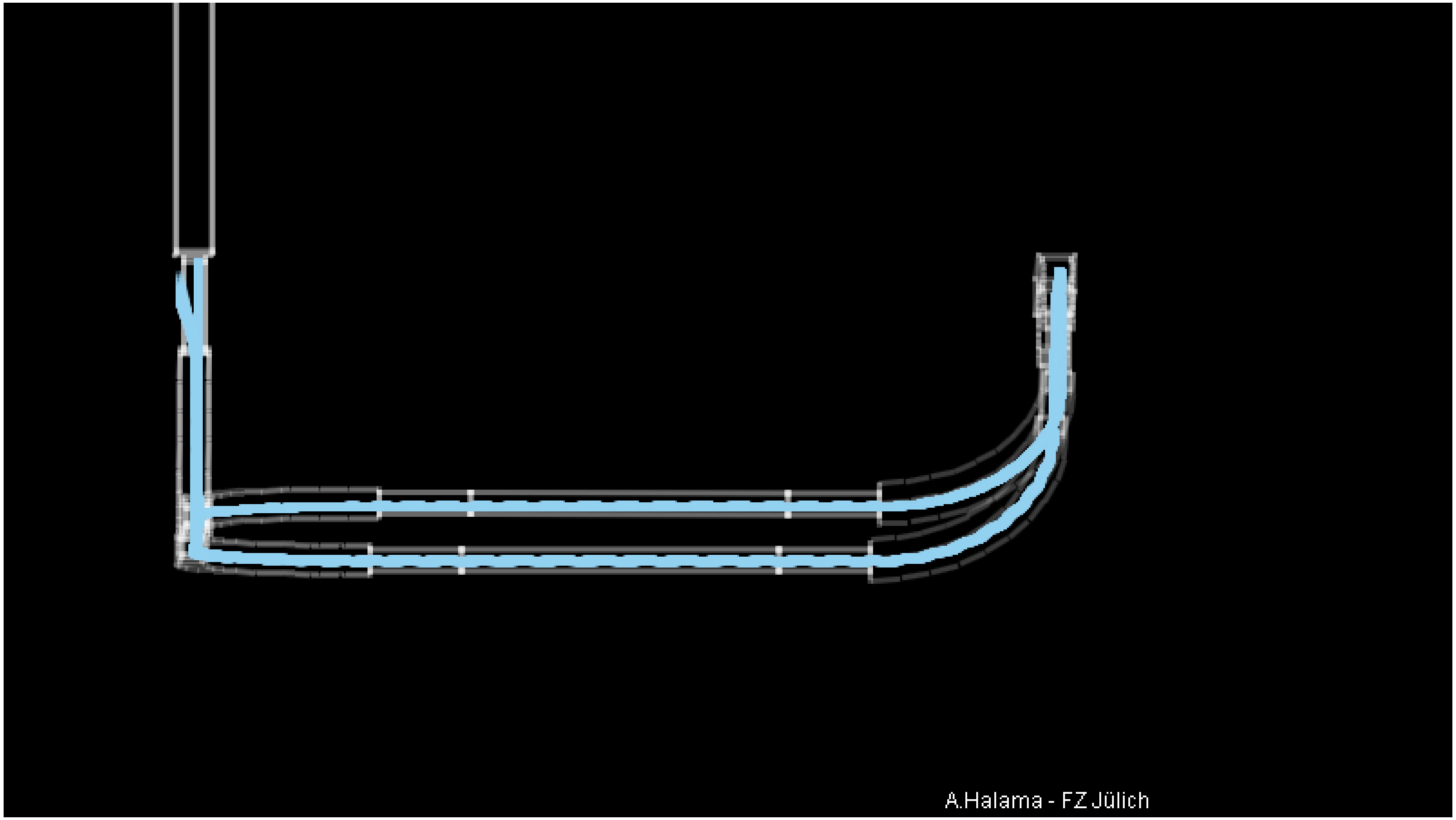
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